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Forensic Engineering Investigations of Residential Clothes Dryer Fires

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Abstract

Residential clothes dryers are common in the United States, and thousands of residential fires involving clothes dryers occur each year. Forensic engineers are called upon to conduct scientific analyses of the causative factors in these fires. Forensic engineering investigations of clothes dryer fires consider design, installation, use, and maintenance of clothes dryers as well as evaluate ignition sources, first fuel ignited, fire containment and fire spread. A forensic engineering methodology for investigation of clothes dryers will be presented in this paper, drawing on experience from hundreds of residential clothes dryer fire investigations.

Keywords

Clothes dryer, lint, self-heating, dryer exhaust duct, transition duct, combustible plastic, forensic engineering

Introduction

The purpose of this paper is to provide information and general guidelines to the forensic engineer for investigating fires involving residential clothes dryers.

After a fire has occurred — and an origin and cause (fire) investigator suspects the area of origin to be at or within a clothes dryer — a forensic engineer is often called upon to investigate whether the appliance caused the fire. In some instances, the forensic engineer is engaged early in the investigation and has the opportunity to participate in the fire scene examination. In other instances, the fire scene examination is performed by other investigators, and the forensic engineer is called upon to evaluate the evidence and participate in laboratory examination of the artifacts. NFPA 921, *Guide for Fire and Explosion Investigations*, provides a reliable and recognized methodology for conducting the investigation[1].

Thousands of fires attributed to clothes dryers occur annually[2]. The proportion of fires involving electric dryers versus gas dryers is roughly proportional to the population of electric dryers in use versus gas dryers in use[3]. This paper addresses conventional vented residential clothes dryers. Condensing clothes dryers and heat pump clothes dryers, which have been recently available in the United States, are not explicitly addressed.

Residential Clothes Dryer Configurations

Typical vented clothes dryers in the United States dry laundry items by pulling a stream of heated air through the laundry load as it is tumbled in a drum rotating on a horizontal axis. The moisture-laden exhaust is discharged to the outdoors through an exhaust duct system. The source of heat can be one or more electric heating elements or a gas-fueled burner. Air is moved through the dryer by an electric motor driven blower located in the base of the dryer cabinet. The blower drive motor also powers drum rotation through a drive belt. The blower is positioned to pull the air through the dryer during operation so that most of the dryer is at a negative pressure during operation. Laundry is loaded into and removed from the drum through a door on the front of the dryer.

The intended normal flow path of air (and combustion products in a gas-heated dryer), through an operating dryer, is generally as follows (**Figure 1**):

- Ambient air (room air) enters the dryer cabinet

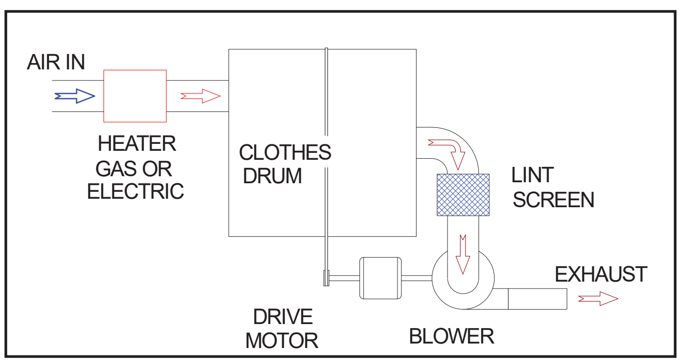

Figure 1
Clothes dryer air flow.

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through small louvered cabinet openings, cabinet seams, and other cabinet openings.

- Air passes through the interior of the dryer cabinet to the inlet of the burner or the electric heater assembly.

- The air is heated as it is pulled through the heater assembly. The heated air (and combustion products in a gas dryer) enters the rear of the dryer drum.

- The heated air is pulled through the drum where it picks up moisture and lint fibers from the laundry load.

- The air/moisture/lint mixture is then pulled through the lint screen trap where the screen collects some of the lint.

- The air with some lint is pulled from the lint trap into the blower.

- The blower pushes the air through the dryer exhaust tube at a positive pressure and into the external exhaust duct.

- The exhaust is discharged to the outdoors through the exhaust duct system.

There are several configurations of dryer design commonly found in use. One type, known as a bulkhead or open-back drum design, uses a drum that is open at its front and rear ends. Each end is supported by a bulkhead. The rear bulkhead forms the rear wall of the drum. There are two common variations of this open-back drum design.

In the first version of the bulkhead/open-drum design, heated air enters the drum through an opening at the upper left portion of the bulkhead and exits the drum through an opening at the upper right portion bulkhead (**Figure 2**):

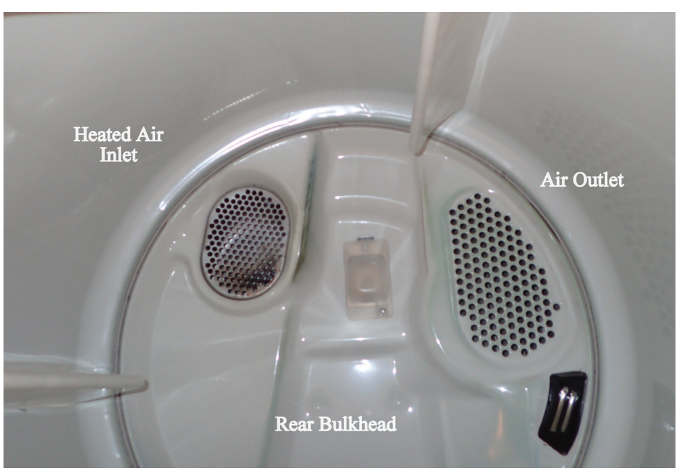

Figure 2
Bulkhead dryer.

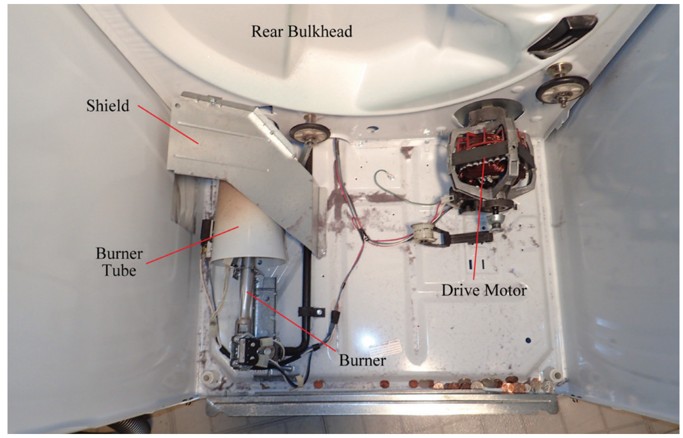

Figure 3
Base of gas-heated bulkhead dryer.

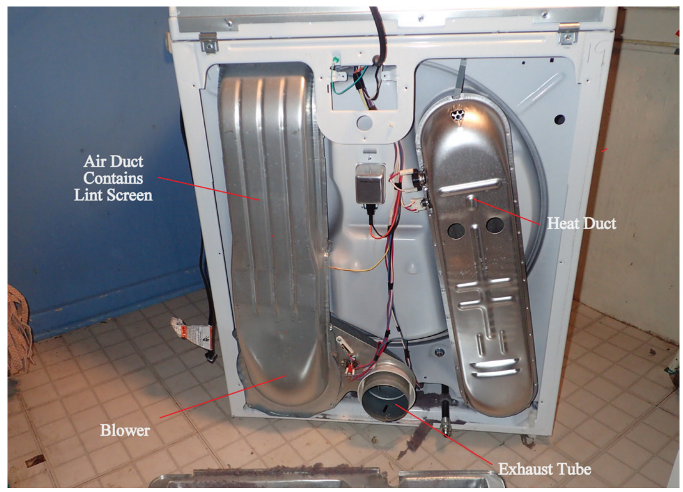

Figure 4
Rear side of bulkhead dryer.

In gas-heated versions of this design, the gas burner is located in the base of the dryer cabinet. The heated air is directed into the drum through a heat duct, which extends up the rear side of the bulkhead from the burner to the inlet opening. In electrically heated versions of this design, the heating elements are contained within a heater box or canister, located in the base of the cabinet or in the vertical heat duct. The discharge opening from the drum to the lint trap is located at the upper right portion of the rear bulkhead. A vertical air duct extends from that opening down to a blower at the lower, right rear corner of the dryer. The lint trap is positioned within that air duct. The blower discharges the exhaust through a horizontal, 4-inch-diameter duct on the rear side of the dryer (**Figures 3** and **4**).

Another variation of bulkhead/open-back dryer differs from the above described bulkhead dryer in that the location of the air discharge and lint trap is at the lower front edge of the drum. An air duct extends from that opening to a blower in the base of the cabinet. The lint trap is positioned within that air duct. The blower discharges the exhaust through a horizontal 4-inch-diameter duct on the rear side of the dryer (**Figures 5** and **6**).

In gas-heated dryers of this type, the gas burner is located in the base of the dryer cabinet. In electrically heated versions of this design, the heating elements are contained within a heater box or canister, also located in the base of the dryer. The heated air is directed into the drum through an opening in the upper right portion of the bulkhead. A heat duct extends up the rear side of the bulkhead from the burner to the opening (**Figure 7**).

Another dryer configuration is commonly known as a ball hitch or closed-back drum dryer. In a ball hitch dryer, the rear end of the drum is enclosed by a perforated metal sheet, which rotates with the drum. The front end of the drum is supported by the front cabinet panel. The rear end is supported by a rear drum support shaft and ball hitch, which extends from the center of the rear side of the drum (**Figures 8** and **9**) to a support bearing (**Figure 10**) on the rear wall of the cabinet. In one gas-heated ball hitch design, a burner tube is located at the lower left portion of the cabinet base. A heat duct extends upward from the burner discharge to a heater pan, located on the rear side of the drum. The heater pan is a vertically oriented shallow cylinder located on the rear side of the drum (**Figure 11**). Heated air and combustion products flow from the burner into the heater pan and then through the perforations in the rear side of the drum. The discharge opening and lint trap are located at the lower front edge of the drum (**Figure 12**). Exhaust air is directed from the drum to the blower through an air duct (**Figure 13**). In electrically heated ball hitch dryers, the electric heating element is arranged in a circular pattern in the heater pan directly behind the drum.

In all of the dryer configurations described above, the dryer operating cycle is controlled by electro-mechanical cycle timer controls or electronic control systems. The normal regulation of the dryer temperature and cycling of the heat source is controlled by an operating thermostat, positioned to measure the temperature of the air exiting the dryer drum. A typical thermostat control is set to open at 155°F and close at 135°F. Newer electronically controlled dryers use a thermistor in place of a mechanically actuated switch.

All of the described dryer configurations are also equipped with a high temperature limiting device that functions independently of the primary temperature control device. In all of these configurations the high temperature limiting device is located between the gas or electric heater and the inlet of the drum.

In many clothes dryer models, one or more additional temperature-limiting devices are included. These additional temperature-limiting devices are of the manual-reset or non-resettable (single use) type, are not accessible to the user without disassembling the dryer, and require manual reset or replacement before continued use of the dryer.

There are many variations of control arrangements in

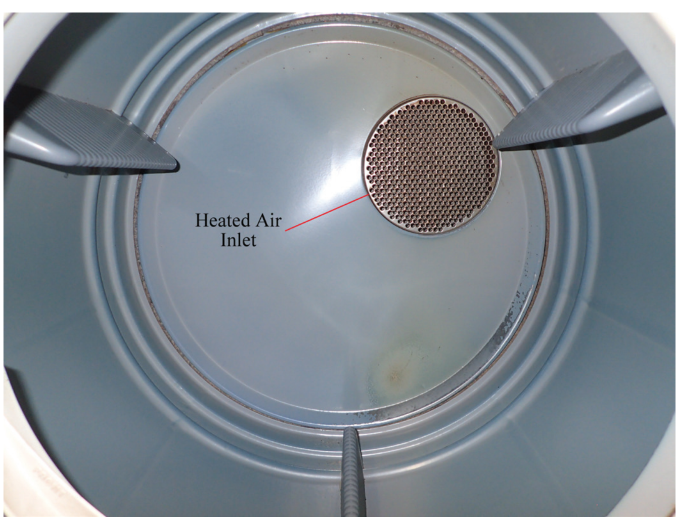

Figure 5
Variation of bulkhead dryer.

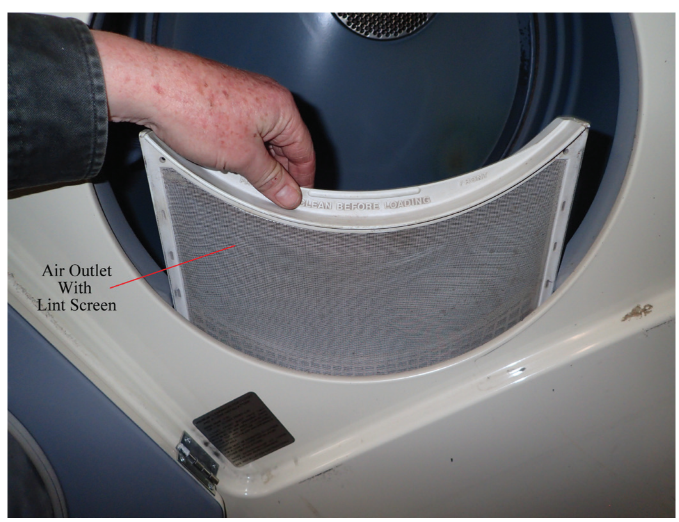

Figure 6
Variation of bulkhead dryer.

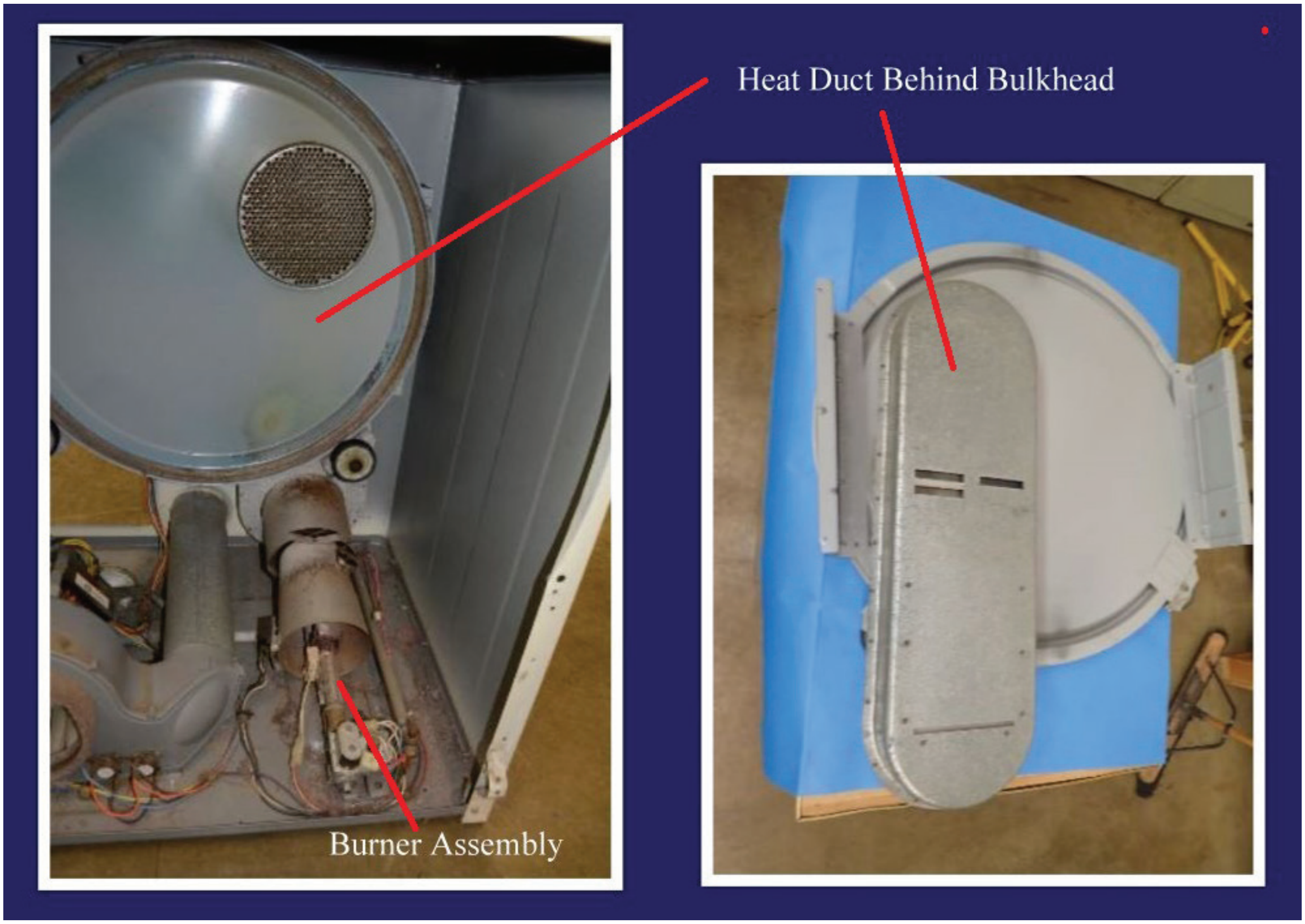

Figure 7
Variation of bulkhead dryer.

Figure 8
Rear side of ball hitch dryer drum.

Figure 9
Ball hitch.

Figure 10
Rear bearing assembly.

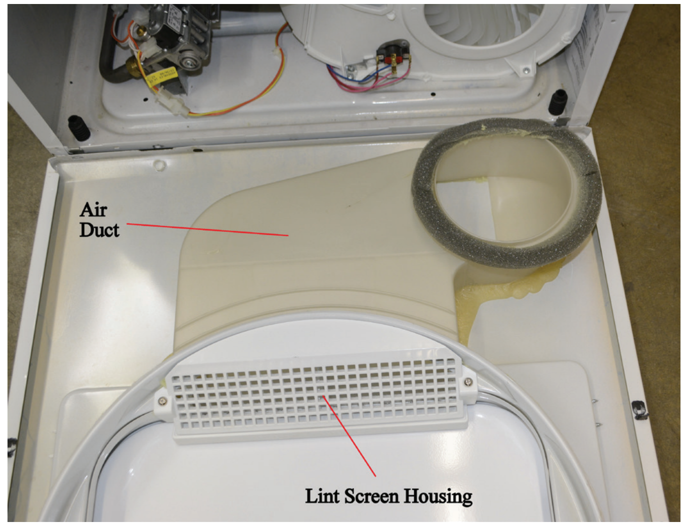

Figure 13
Ball hitch dryer.

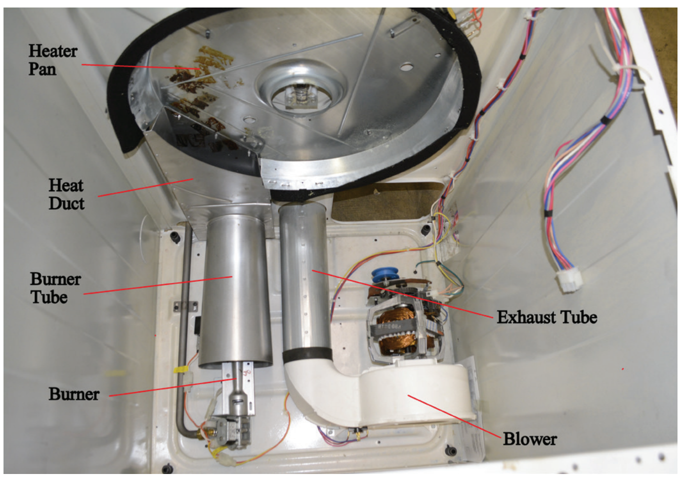

Figure 11
Base of gas ball hitch dryer.

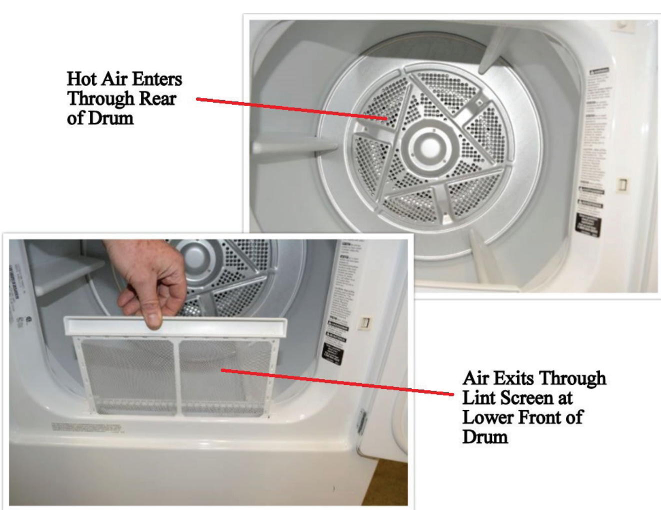

Figure 12
Ball hitch dryer drum.

residential clothes dryers. It is recommended to obtain a control schematic and parts list for the dryer model involved in an investigation before performing a detailed examination of the dryer.

In a normally operating dryer, the drum temperature will be slightly higher than the thermostat setting, likely somewhere between 150°F and 180°F. When the exhaust duct is restricted, airflow through the dryer is reduced. Since heated air is not being effectively moved through the drum, the drum temperature will actually be lower in a blocked vent condition. The temperature upstream of the drum, in the heater pan or heat duct, will increase. Instead of the heater cycling on and off in response to the operation of the operating thermostat, it cycles on and off in response to the operation of the safety thermostat (high temperature limit switch).

Airflow through the dryer can also be reduced by a large load or by leaks in dryer seals, upstream of the blower. Those conditions can also cause a dryer to cycle on the safety thermostat instead of the operating thermostat, even in a properly vented dryer.

Examination of the safety thermostat switch contacts will indicate if the switch has been cycling. The contacts on the high temperature limit switch from a gas dryer will generally have less damage, since the switch interrupts the low current from the gas valve coils. The switch contacts on a high temperature limit for an electric dryer will show relatively greater damage due to interrupting the larger current of the electric heating elements. **Figures 14** and **15** show the high temperature limit contacts from a

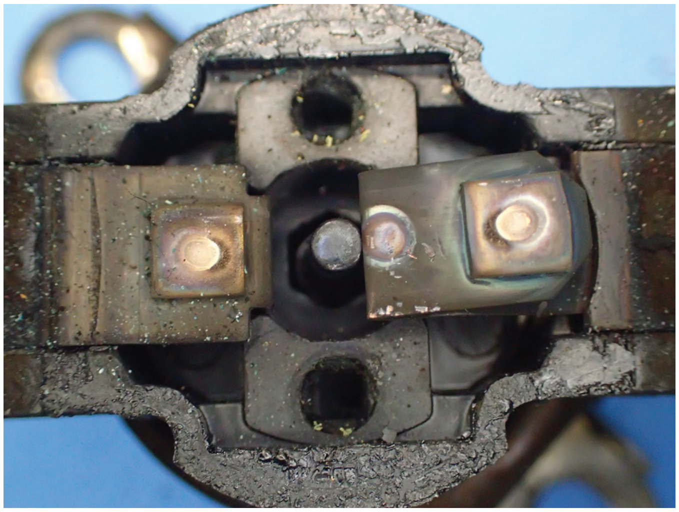

Figure 14
Contacts of gas dryer safety thermostat.

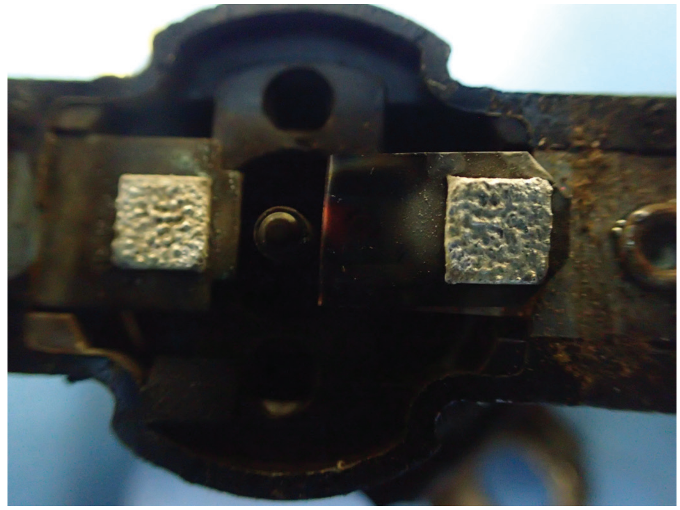

Figure 15
Contacts of electric dryer safety thermostat.

gas and an electric dryer.

Clothes Dryer and Related Standards

Residential clothes dryers are constructed and tested to comply with voluntary consensus standards. Electrically heated dryers fall under the scope of UL 2158 – Electric Clothes Dryers[4]. Gas-heated dryers fall under the scope of ANSI Z21.5.1 – Gas Clothes Dryers[5].

The March 2009 version of UL 2158 incorporated requirements for fire containment tests for electric dryers. The compliance date was March 20, 2013. Four separate fire containment tests are necessary to meet the requirements of the standard, including a drum load fire containment test with the dryer in operation, a drum load fire containment test with the dryer stopped, a base fire containment test with the dryer in operation, and a base fire containment test with the dryer stopped.

The ANSI Z21.5.1 standard incorporated similar fire containment testing requirements in the 2015 edition of the standard including four separate fire containment tests for each dryer design.

UL 2158A – Clothes Dryer Transition Ducts[6] contains requirements for the transition ducts used to connect a dryer exhaust to the permanent duct system in a residence. The first edition of this standard was published in 2011. Transition ducts were previously listed under UL Subject 2158A, Outline of Investigation for Clothes Dryer Transition Ducts[7], which was first published in 1996.

UL 94 – Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances[8] provides a method for rating the ignition characteristics of plastic materials. Flame class ratings range from the minimum of HB through the maximum of 5VA and 5VB. UL 2158 requires that plastic materials in clothes dryers meet one of three flammability classifications in UL 94, including the horizontal burn classification of HB or the more stringent vertical burn classifications of 5VA or 5VB.

Building Code Requirements for Residential Clothes Dryers

In most locations, residential clothes dryers are required to be installed in compliance with local building codes. UL 2158 requires that the installation instructions include a statement to install the clothes dryer according to the manufacturer's instructions and local codes. ANSI Z21.5.1 requires that the installation instructions include a statement that the installation must conform with local codes, or in the absence of local codes, with the National Fuel Gas Code, ANSI Z223.1/NFPA 54[9].

One frequently adopted model code is the International Residential Code (IRC)[10]. Requirements in the IRC for clothes dryers include the following:

- Clothes dryers shall be exhausted in accordance with the manufacturer's instructions;

- Dryer exhaust systems shall be independent of all other systems;

- Exhaust ducts shall terminate outside the building and be equipped with a backdraft damper;

- Terminations shall not contain screens;

- Exhaust ducts shall be constructed of metal and shall have a smooth interior finish;

- Clothes dryer transition ducts shall be metal, be limited to a length of 8 feet and shall be listed and labeled for the application;

- The maximum exhaust duct length shall not exceed 25 feet;

Exception: Where the make and model of the dryer is known the length shall be in accordance with the manufacturer's instructions;

- Installations exhausting more than 200 cfm shall be provided with a source of air for combustion and ventilation (make-up air).

- Closet installations require an opening with an area not less than 100 square inches.

ANSI Z223.1/NFPA 54 includes the following requirements for residential clothes dryer installations:

- Clothes dryers shall be exhausted to outdoors;

- Make-up air shall be provided in accordance with the manufacturer's installation instructions;

- Dryer exhaust ducts shall be independent from other vents and shall not be connected to an attic, crawl space or similar concealed space;

- Exhaust ducts shall be constructed of rigid metallic material. Transition ducts shall be listed for that application or installed in accordance with the manufacturer's installation instructions.

Clothes Dryer Exhaust Duct Systems

The exhaust duct system for a residential clothes dryer will generally contain a permanent duct system and a transition duct, which connects the dryer exhaust outlet to the permanent duct system. The permanent exhaust duct system is often installed during the construction of the residence and is concealed within the construction. The transition duct is often installed at the time the dryer is installed or may be re-used from a previous dryer.

Clothes dryer installation instructions contain recommendations for the exhaust duct system. Most instructions recommend that the duct system be constructed of 4-inch-diameter (minimum) rigid metal or flexible metal duct. The instructions will include one or more charts indicating maximum duct length and number of 90 degree elbow combinations for each type of duct. Maximum duct length is also dependent on the type and size of exhaust hood used in the system.

Many manufacturers include an alternate method of determining if a duct system is acceptable. That method is to measure the back pressure in the exhaust duct where it connects to the dryer with a manometer. The back pressure is measured with the dryer operating in a non-heat mode. Maximum allowable back pressure differs between manufacturers and dryer models. For example, Frigidaire permits a maximum back pressure of 0.75 inches of water column for most of its clothes dryer models. Samsung permits a maximum back pressure of 0.83 inches of water column for some of its dryer models.

The installation instructions provided with many newer dryers have more limitations for the use of flexible metal duct. For example, a 2010 installation instruction manual for a Whirlpool clothes dryer eliminates a flexible metal length chart and does not permit flexible metal vent to be installed in concealed spaces. Newer Frigidaire instructions limit flexible metal vent to a maximum length of 8 feet.

Transition ducts can be found constructed of rigid metal duct, flexible metal duct, or flexible plastic duct. Each type of transition duct has advantages and disadvantages. Although manufacturers recommend using rigid metal duct or flexible metal duct, a large portion of dryers are installed with flexible transition ducts, including UL-listed transition ducts, flexible foil ducts, and flexible vinyl ducts. According to a U.S. Consumer Product Safety Commission Survey, 42% of respondents indicated that their dryer duct was "flexible accordion type foil," and 16% reported that their dryer duct was constructed of "accordion-type white plastic"[11]. Transition ducts are not permitted to be installed in concealed spaces.

While rigid metal duct is preferred for dryer exhaust, it has some disadvantages when used for transition duct. It is difficult to obtain a good seal between the dryer exhaust outlet and the first transition duct fitting. It can be very difficult (if not impossible) to access both ends of the transition duct when installing the dryer. This is particularly true for under-counter installations, closet installations, and

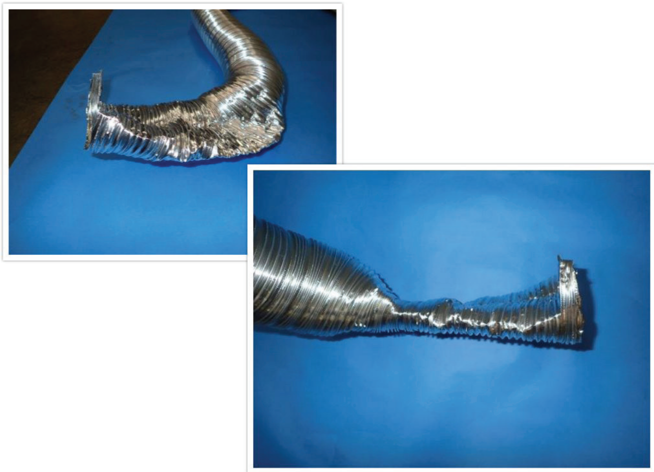

Figure 16
Crushed flexible metal duct.

alcove installations.

Flexible metal duct also has disadvantages. The interior surface has ridges that can collect lint. It has limited puncture resistance and poor resilience. When crushed or kinked during installation — or when the dryer is moved for cleaning — it will not return to its original shape (**Figure 16**). Recall that building codes, such as the International Residential Code and National Fuel Code, require clothes dryer transition ducts be listed for the application. Most flexible metal duct is not listed as clothes dryer transition duct.

UL 2158A contains requirements for clothes dryer transition duct. The standard includes tests for surface burning, flame resistance, bending, corrosion resistance, puncture resistance, impact resistance, tension, and torsion. Most UL-listed transition ducts that are currently available are flexible foil style ducts. UL-listed flexible foil transition ducts are also subject to being crushed or kinked but have a better ability to return to their original shape when repositioned.

UL-listed flexible foil clothes dryer transition duct is permitted by the installation instructions of many clothes dryer manufacturers for some of their models, including Whirlpool, Frigidaire (Electrolux), GE, Samsung, and LG. **Figure 17** contains a list of some dryer manufacturers that permit the use of UL-listed flexible foil transition ducts.

Lint

Lint is generated from laundry items such as clothing, bedding and towels. During use, movement and abrasion breaks down the fibers of the laundry items. Washing creates lint through mechanical agitation of the laundry load and the action of temperature, detergents and other additives. Additional lint is created in the dryer by the mechanical tumbling action with heat and air flow. Lint particles that become separated from the laundry items become airborne in the dryer. Those lint particles can be collected in the lint trap, discharged through the exhaust duct, and/or deposited within the dryer. Dryer lint can also contain pet hair and other contaminants from the load. Fabric abrasion tests have shown that 100 percent cotton fabrics experience a greater mass loss than 50/50 cotton/polyester fabrics[12]. **Figure 18** shows ignition temperatures for various textile fibers and textiles.

Dryer Manufacturer	Transition Duct Instructions
Whirlpool	If flexible metal (foil type) duct is installed, it must be a of a specific type identified by the appliance manufacturer as suitable for clothes dryers.
Frigidaire	In Canada and the United States, if metal (foil type) duct is installed, it must be of specific type identified by the appliance manufacturer as suitable for use with clothes dryers and in the United States must also comply with the Outline for Clothes Dryer Transition Duct, UL standard 2158A.
GE	In Canada and the United States, only the flexible metal (foil-type) ducts that comply with the “Outline for Clothes Dryer Transition Duct Subject 2158A” shall be used.
LG	Rigid or semi rigid metal ducting is recommended for use between the dryer and the wall. In special installations when it is impossible to make a connection with the above recommendations, a UL-listed flexible metal transition duct may be used between the dryer and wall connection only.
Samsung	In the United States, only those foil-type flexible ducts, if any, specifically identified for use with the appliance by the manufacturer and that comply with the Outline for Clothes Dryer Transition Duct, Subject to 2158A, shall be used.

Figure 17
Clothes dryer instructions (summarized from user manual) permitting UL-listed flexible foil transition duct.

Material	Ignition Temperature °F	Source
Wool	1112	Plastics Flammability Handbook[13]
Cotton Fibers	500	Ignition Handbook[14]
	490-750	NFPA Handbook - 19th Edition – Table 8.5.5[15]
Cotton	662	Plastics Flammability Handbook
	662	Khattab[16]
Polyester Fibers	680-750	NFPA Handbook - 19th Edition – Table 8.5.5[23]
Polyester	896	Plastics Flammability Handbook
Cotton/Polyester 50/50 Blend	842	Khattab

Figure 18
Textile fiber ignition temperatures.

Cotton has a heat of combustion of 19 KJ/g (8169 Btu/lb) and polyester has a heat of combustion of 24 KJ/g (10,318 Btu/lb)[13]. However, lint density is very low, and the resulting fuel load created by accumulated lint is low.

Lint Accumulation

Lint begins to accumulate in clothes dryers upon first use, even when the dryer is properly vented, and the lint screen is cleaned after each usage[17]. Lint also accumulates in the base of the dryer cabinet, on component surfaces and on wiring harnesses (**Figure 19**). In ball hitch dryers, lint also can accumulate in the heater pan and on the rear side of the drum. Reduced airflow through the dryer is likely to cause increased accumulation of lint. As lint accumulates in the internal air flow passages of a dryer and exhaust system it creates additional restriction to air flow. Lint accumulated on gas burner air intake openings can alter the size and shape of the burner flame.

Multiple potential paths are available for lint to travel from the laundry load to the interior of the dryer. During each cycle of the dryer, lint accumulates on the lint screen. As the lint screen becomes blocked, airflow through the dryer decreases. A significant amount of lint bypasses the lint screen and accumulates in the air duct, blower, exhaust tube, and external exhaust duct. Recall that the upstream of the blower, the dryer air flow path is at a negative pressure and downstream of the blower, the air flow path is at a positive pressure. Any leaks at internal seals within the dryer, downstream of the blower, will result in leakage of lint-laden exhaust into the base of the dryer. This leakage will increase with increased exhaust duct restriction. One such seal is between the blower discharge and exhaust tube (**Figure 20**).

The exhaust duct external to the dryer also operates at a positive pressure. A leak in that exhaust duct can leak lint-laden exhaust from the duct. On most dryers, cabinet

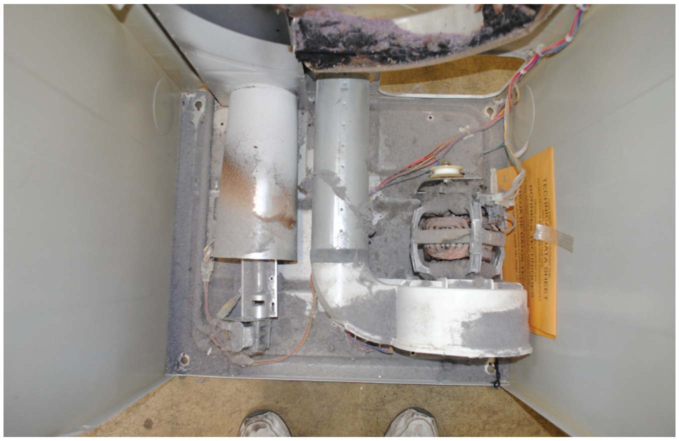

Figure 19
Accumulated lint in base of dryer.

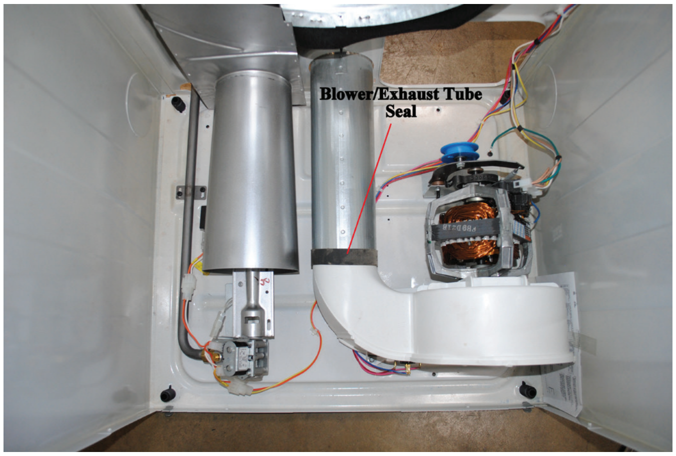

Figure 20
Positive pressure blower exhaust seal.

Figure 21
Exhaust tube and air intake louvers.

Figure 22
Non-crushed seal.

air intake openings are located on the back of the dryer near the first exhaust duct connection to the dryer. This has the potential to draw lint-laden exhaust back into the dryer cabinet through the air inlet louvers (**Figure 21**).

Air leaks at seals on the negative pressure side of the blower (upstream of the blower) can also lead to additional lint accumulation within the dryer and alter the patterns of lint accumulation within the dryer. For example, a leak at the front drum seal will permit air from the dryer cabinet to enter the front end of the drum. This air leaking into the drum will displace air that is normally pulled through the burner or heater box and through the rear of the drum. A large leak could result in increased temperatures upstream of the drum. In ball hitch dryers, this reduced airflow can cause additional lint accumulation behind the drum. A leak at the seal between the air duct (lint chute) and blower will have a similar effect. A leak at seal on the negative pressure side of the air stream will also act like a vacuum, pulling lint laden air to the leak. That can result in an abnormal accumulation of lint around the seal.

Figure 23
Crushed seal.

For example, in ball hitch dryers, the rear of the drum is supported by a single shaft in a bearing. The front end of the drum is supported by the front drum seal. During use, the seal can become crushed and create a gap to open at the lower end of the drum (**Figures 22, 23** and **24**).

Ball hitch-style dryers are equipped with a heater pan behind the drum. Lint can accumulate in the heater pan of ball hitch dryers. Larger accumulations occur in gas ball hitch dryers than in electric ball hitch dryers due to the presence of a seal between the heater pan and rear of the drum on the gas dryers (**Figure 25**).

Exemplar dryers can be examined to determine lint accumulation patterns and the amount of lint accumulated in a dryer. The gas dryer shown in **Figures 19** and **25** was in operation for eight years by a family of four. In that time, the interior of the dryer cabinet was not cleaned. The total weight of accumulated lint in the dryer at the end of that eight years was 0.256 pounds. In a similar model gas dryer operated for more than 10 years, with no

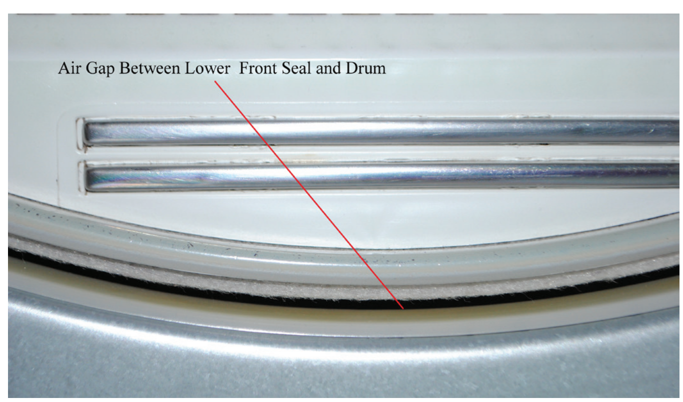

Figure 24
Gap created by crushed seal.

Figure 25
Charred lint in the heater pan of a ball hitch dryer.

cleaning of the interior of the dryer cabinet, the weight of the accumulated lint was 0.086 pounds. The fuel loads provided by the lint in those dryers, assuming 100 percent cotton, would be only 2091 Btu and 702 Btu, respectively.

Accumulated lint in a clothes dryer creates a risk of fire. Even though the lint provides a relatively small fuel load it can spread fire to other combustible materials in the dryer such as the load and/or combustible plastic components.

Cleaning and Maintenance

The UL 2158 standard for electric clothes dryers and the ANSI Z21.5.1 standard for gas clothes dryers contain requirements for the content in dryer instruction manuals. The UL standard requires that the instruction manual contain an instruction to clean the lint screen before or after each load and that the interior of the appliance and the exhaust duct should be cleaned periodically by qualified service personnel. The ANSI standard requires that the maintenance instructions include instructions for cleaning of lint screens and for periodic examination of exhaust systems. Many manufacturers recommend that cleaning should be performed "periodically." Other manufacturers recommend that cleaning be performed at intervals ranging from 12 to 18 months.

Cleaning of the interior of a clothes dryer is intended to remove accumulated lint. It requires partial disassembly/opening of the dryer cabinet and removal of the drum. Paying qualified service personnel to perform this procedure creates a significant expense over the life of the dryer. According to a U.S. Consumer Products Safety Commission Survey only 20% of respondents indicated that the inside of their dryers were ever cleaned.

Self-Heating of Dryer Load

According to NFPA 921, self-heating is the result of exothermic reactions occurring spontaneously in some materials under certain conditions, whereby heat is generated at a rate sufficient to raise the temperature of the material. Self-ignition is ignition resulting from self-heating, synonymous with spontaneous ignition.

In the context of clothes dryer fires, the mechanism of spontaneous ignition is generally the following:

- The laundry load consists of combustible materials.
- The load is contaminated by vegetable oils, certain animal fats or petroleum products.
- An exothermic oxidation reaction of the contaminant generates heat.
- Heat is trapped in the load, increasing the internal temperature,
- The increased temperature increases the rate of the reaction, further increasing the temperature.
- Smoldering ignition occurs inside the load.
- Possible transition to flaming ignition.

A number of factors must be present for spontaneous ignition to occur:

- The contaminant substance must be capable of self- heating.
- There must be enough contaminant so that self-heating is not limited by depletion of the contaminant before ignition occurs.
- The load must be large enough to contain the heat yet permit sufficient air to continue the reaction. The heat generation must exceed the heat loss.
- The load must be sufficiently porous to permit air into the interior of the load.
- There must be sufficient time after the dryer has stopped operating for self-heating to progress to ignition (hours).

Under normal circumstances, the airflow through an operating dryer will remove the heat generated by an exothermic reaction occurring in the load. Therefore, a fire caused by self-heating of the load will not occur while the dryer is in operation.

The potential for a laundry load to self-heat to ignition is greatly enhanced by heating the load during the dryer operating cycle. Most dryers have a cool-down period at the end of the drying cycle. The benefits of this cool down cycle are often eliminated when the load is too large to be adequately cooled during the cool down cycle, when the drying cycle is interrupted before the cool down cycle is started or completed (for example when a user opens the dryer door to remove one article before the dryer cycle is complete) or when the heated load is removed from the dryer before cooling and placed in a clothes basket or a pile on the floor or counter. Even the act of folding and stacking the laundry may not permit it to cool sufficiently.

When self-heating, progressing toward ignition occurs, large amounts of acrid smoke are likely to be produced[18, 19]. It is likely that smoke would be observed by any occupants present.

Tests were performed by Sanderson and Schudel[20] to determine if dryer lint self-heated when exposed to elevated temperatures. No self-heating of dryer lint was observed in their tests.

When a suspected cause of a clothes dryer fire is self-heating, it may be possible to collect a sample and have it analyzed to check for materials prone to self-heating. It may also be possible to collect a sample of water from the clothes washer drain hose for analysis.

Fuel Analysis

According to NFPA 921 – 2017, "Fuel analysis is the process of identifying the first (initial) fuel item or package that sustains combustion beyond the ignition source and identifying subsequent target fuels beyond the initial fuel."

In many residential clothes dryer fires, the first fuel ignited is lint. However, ignition of lint alone is unlikely to pose a significant fire hazard in a clothes dryer. To become a significant fire hazard, likely to create large amounts of smoke or spread the fire beyond the dryer, the lint must ignite secondary fuels such as leaking fuel gas, combustible components of the dryer or the laundry load. In many circumstances, ignition of the load by lint ignition alone is difficult, such as in the early part of the cycle when the load is still wet or damp.

The potential for fuel gas feeding the fire, after the dryer has stopped operation, can be evaluated by leak testing the gas supply pipe and control valve assembly. If a leak is found, the flow rate should be measured.

The use of plastics in dryer components can provide a significant fuel load in a dryer. As mentioned, UL 2158 requires that plastic components meet one of three of the UL94 flammability classifications. Those classifications include HB (horizontal burn) or the more stringent vertical burn classifications of 5VA and 5VB. Components constructed of HB rated plastics may ignite more quickly when exposed to ignited lint or an ignited load. HB plastic will continue to burn even if the initial ignition source is removed and produce hot molten plastic that can spread in the base or flow out of the dryer cabinet and continue to burn outside the dryer[21]. A material classified as 5VA or 5VB is subjected to a flame ignition source that is approximately five times more severe than that used in an HB test. Also, the 5V specimens may not drip any flaming particles. 5V materials tend to self-extinguish when the ignition source is removed[22].

The fuel load provided by combustible plastic components within the dryer can be determined several ways. Information may be available directly from the manufacturer or through the discovery process. Another approach is to obtain exemplar parts from an exemplar dryer or purchase replacement parts. The parts can then be weighed, and data regarding heat of combustion of the material can be used to determine the maximum available fuel load provided by the component. Consideration should be given to non-combustible mineral fillers used in the material, which may reduce the fuel load. The UL 94 flame class ratings for the components should be determined.

For example, the plastic components in an exemplar dryer were removed and weighed. The combined weight of the blower, air duct, lint trap housing and lint trap was about 3.4 pounds. The material used for the parts was polypropylene filled with 20 percent non-combustible material. Polypropylene has a heat of combustion of 18,917 Btu/lb and the filled material had a heat of combustion of 15,134 Btu/lb. This would provide and available fuel load from the plastic components of 51,456 Btu[13]. In comparison, the accumulated lint in the dryer shown in **Figures 19** and **25** provided a fuel load of about 2091 Btu.

Replacement of plastic materials with metal would completely eliminate the fuel load provided by the plastic materials regardless of the flammability classification of the plastic materials. For example, some manufacturers utilized steel in the construction of lint trap ducts and blower housings.

If the unburned load is removed from the dryer at the initial discovery of the fire — or if the load is minimally fire damaged — it is obvious that the load would have provided little or no fuel for the fire. If the load is involved in the fire, it should be examined to determine what was in the load. The users may be able to provide information regarding the contents of the load. If the load contents can be determined, the available fuel load can be determined using published heat of combustion values for the materials involved.

In most residential clothes dryers not caused by self-heating of the load, the first fuel ignited is lint. However, ignition of lint alone is unlikely to pose a significant fire hazard in a clothes dryer. Therefore it is important to identify and analyze subsequent target fuels beyond the initial fuel.

Case Studies

Case Study 1 – Ignition of Lint in an Electric Dryer

A fire occurred in a four-year-old electric dryer during operation about 15 minutes after a drying cycle was started. The fire was witnessed by the user. The dryer vent system complied with the manufacturer's installation instructions. The dryer load consisted of a twin size fleece blanket. The blanket was minimally damaged by the fire. From a detailed lab exam of the dryer and other artifacts, it was determined that lint was ignited by the energized electric heating element and spread the fire to the plastic components. Most of the combustible plastic components, including the blower and air duct, were consumed (**Figures 26** and **27**).

Case Study 2 – Ignition of Lint in a Gas Dryer

A fire occurred in a four-year-old natural gas fueled clothes dryer during operation (**Figure 28**). The fire was discovered and witnessed by the user several minutes after it had been placed in operation. Upon discovery of the fire, the user stopped the dryer and removed the unburned, wet load from the dryer. From a detailed lab exam of the dryer and other artifacts, it was determined that the fire resulted from ignition of lint within the dryer (**Figure 29**). The source of the ignition was the gas burner. The fire spread to the combustible plastic components, including

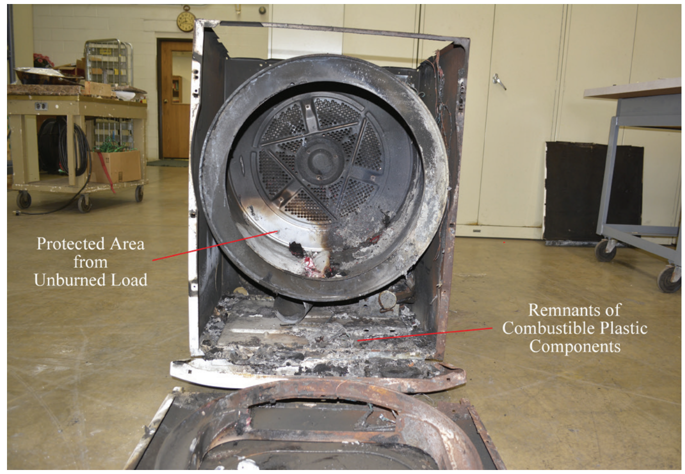

Figure 26
Front of partially disassembled electric dryer.

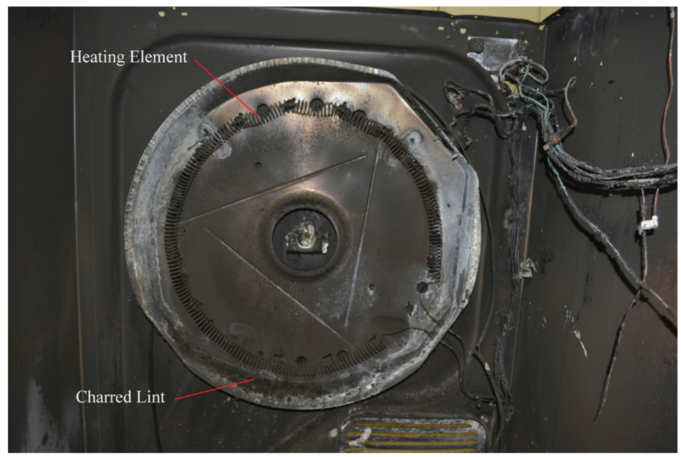

Figure 27
Heater pan of electric ball hitch dryer showing heating element and accumulated lint.

Figure 28
Dryer cabinet showing thermal damage from plastic fuel load.

the blower and air duct, and most of those components were consumed (**Figures 30** and **31**).

Figure 29
Heater pan of dryer showing accumulated lint.

Figure 30
Base of dryer showing mostly consumed combustible plastic components.

Figure 31
Base of dryer showing mostly consumed combustible plastic components.

Case Study 3 – Rear Drum Bearing Failure in An Electric Dryer

A 10-year-old electric ball hitch dryer started on fire while in operation. The homeowners witnessed the fire. Examination of the dryer determined that the rear drum support bearing had worn, permitting metal-to-metal contact between the rear drum support shaft and the bearing bracket (**Figure 33**). Eventually, the shaft was severed (**Figure 32**), and the rear of the metal drum baffle contacted the energized heating element. The resulting arcing

Figure 32
Severed ball hitch.

Figure 33
Wear on bearing bracket.

Figure 34
Load with minimal fire damage.

event and dispersal of molten metal into the dryer ignited lint within the dryer. The load had minimal fire damage (**Figure 34**). Most of the combustible plastic components burned (**Figure 35**).

Case Study 4 – Bra Underwire Contact with Energized Electric Heating Element

A nine-year-old electric dryer started on fire while in operation. A homemaker doing laundry heard a "clank" noise from the dryer and investigated. She opened the dryer door and did not initially observe anything wrong but could smell smoke. She removed the laundry load from the dryer, which was not burning or damaged. She got down low and saw flames under the dryer. Examination of the dryer revealed that a loose underwire from a bra had worked its way through the air holes in the rear of the drum and had contacted the energized heating element directly behind the drum. The underwire was welded to the element, and a large portion of the element was damaged (**Figures 36** and **37**). The resulting arcing event and dispersal of molten metal into the dryer ignited lint within the dryer. Most of the combustible plastic components burned. The dryer exhaust vent complied with the installation instructions.

Case Study 5 – Self-Heating of Laundry Load (Kitchen Towels)

Two identical laundry centers (washer/dryer combination machines) were in use in a high school home economics department (**Figure 38**). Both machines were less than one-year-old at the time of the fire. The laundry centers were used to wash and dry kitchen towels from cooking classes. This activity likely contaminated the towels with vegetable oils. Multiple brands and varieties of vegetable oils were found in the kitchen areas. On the day of the fire, both dryers were started with loads of kitchen towels after the last class of the day. A fire was discovered in one of the dryers several hours later, when the fire sprinkler system activated. Fire damage was limited to the one dryer. The other dryer was not fire damaged (**Figures 39** and **40**). Both dryers were examined in detail. In the fire damaged dryer, the damage was mostly limited to the drum. Minimal lint

Figure 35
Consumed plastic components.

Figure 36
Bra underwire welded to heating element.

Figure 37
Bra underwire welded to heating element.

Figure 38
Two identical model laundry centers.

Figure 39
Fire-damaged dryer.

Figure 40
Undamaged dryer and load.

Figure 41
Front of dryer.

was found in both dryers. No testable remnants of the load remained in the fire damaged dryer. However, the towels in both dryers had been used in the same manner with the same kitchen products. A sample of the towels of the unburned dryer was sent out for chemical analysis. The presence of unsaturated vegetable-type oils was detected in the sample. It was concluded that the fire was likely caused by self-heating of the vegetable oil-contaminated towels.

Case Study 6 – Dryer Drum Failure

A user discovered a fire in an operating gas clothes dryer (**Figure 41**). When the fire was discovered, the load was not burning. A detailed lab exam of the dryer found a large amount of charred clothing items in the base of the dryer (**Figure 42**). A large section of the dryer drum at the

Figure 42
Dryer base.

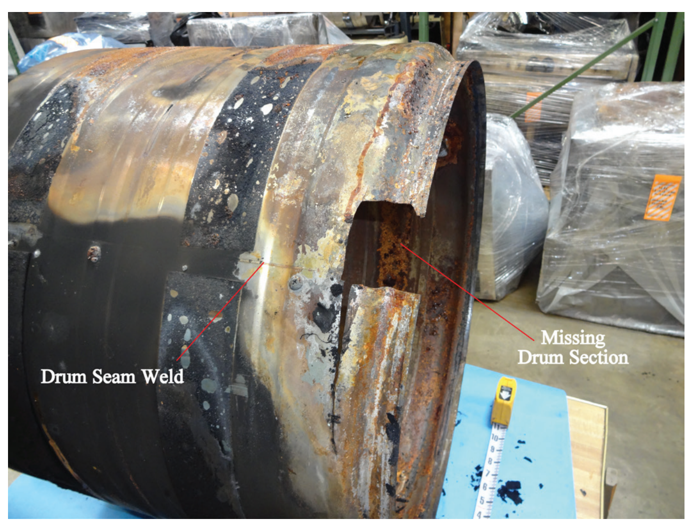

Figure 43
Rear edge of drum showing missing portion.

rear edge had detached from the drum (**Figures 43** and **44**). This missing section permitted small laundry items to fall into the dryer base near the burner assembly and onto the top of the burner tube where they were ignited. One edge of the fractured section was part of the longitudinal drum seam weld.

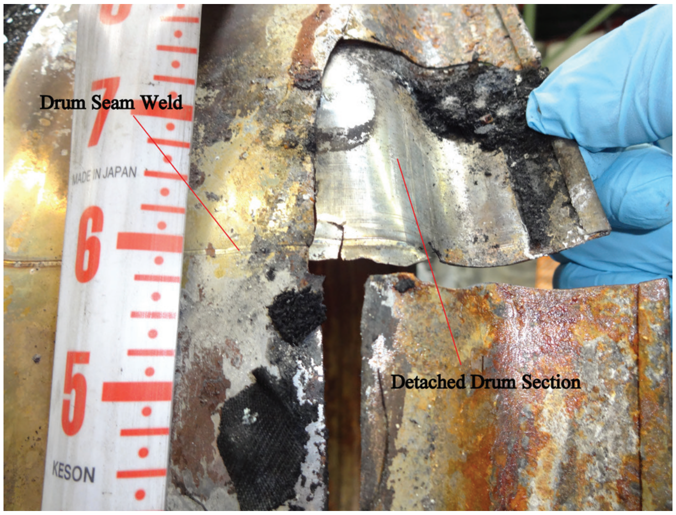

Figure 44
Rear of drum showing separated section of drum.

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